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DRAWINGS ATTACHED

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(19) THE PATENT OFFICE LONDON

(54) A RADIAL TIRE BREAKER AND STRIPS OF MATERIAL THEREFORE

(71) We, BRIDGESTONE TIRE KABUSHIKI KAISHA of No. 1-1, 1-Chome, Kyobashi, Chuo-Ku, Tokyo, Japan, a company organized according to the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a pneumatic tire breaker, and strips of material therefore, and more particularly to a breaker for a radial tire having carcass plies consisting of cords disposed radially, or substantially along radial planes emanating from the axis of rotation of the tire, which breaker is effective in improving the cornering power of the tire.

In the so-called radial tires, cords of tire carcasses are disposed substantially on radial planes emanating from the axis of rotation of the tire. Such a carcass of the radial tire bears only those loads which are applied thereto along the radial direction of the tire during the running of a vehicle with such radial tires, for instance, by the internal pneumatic pressure of the tire or by impulsive shocks from the outside. Accordingly, it is necessary to provide a suitable reinforcement to supplement the circumferential strength of the radial tire. In fact, a breaker is attached circumferentially of the radial tire for such purposes.

The breaker thus disposed acts to tighten the radially disposed carcass cords from the outside toward to the axis of rotation of the tire. Such tightening action of the breaker is generally referred to as the "belting effect".

The material which is most commonly used in construction of the breaker of radial tires is rayon, because rayon has a larger elastic modulus than nylon and polyester for providing more satisfactory belting effects. Nylon and polyester (e.g., polyethyleneterephthalate) are widely used in the carcass (case) of bias or crossply tires, but the elastic modulus of nylon and polyester is usually too small for use in the breaker of radial tires.

Tests have been carried out on the cornering power of two different types of radial tires on a drum tester, one having nylon breakers and the other having rayon breakers. The tests proved that the cornering power of radial tires with nylon breakers was only 55% of that of the radial tires with rayon breakers. What is meant by "cornering power" is a force generated by a tire in response to centrifugal force applied thereto when the tire makes a turn, and the larger the cornering power is, the easier automobile handling is. Field tests were carried out by mounting the aforesaid two types of radial tires on test automobiles, and it was found that the handling characteristics of the radial tires with nylon breakers were rather poor, and were comparable with the cornering characteristics of regular crossply ties. Thus, nylon is not suitable for use in the construction of breakers of radial tires.

Polyesters (e.g., polyethyleneterephthalate) have increasingly been used in the construction of carcasses of crossply tires due to their excellent physical properties; namely, a higher elastic modulus than that of nylon, freedom from flat spots, high water-resistivity or high chemical stability against water, and high heat-resistivity. In fact, rayon carcasses (cases) have increasingly been replaced by such polyester carcasses (cases) in the case of crossply tires. The elastic modulus of such polyester, however, is not large enough for use in radial tire breakers.

It has been found that polyethylene naphthalate fibers have excellent elastic modulus, as well as the aforesaid advantages of polyester. After a series of tests, it has been possible to determine which polyethylene naphthalate fiber cards possess suitable properties for their being used in the construction of radial tire breakers.

According to one aspect of the invention, there is provided a strip of radial tire breaker material consisting of a rubber sheet reinforced by parallel polyethylene naphthalate fiber cords, each cord having a Young's modulus in the range of from 7.0×10^4 to 27.0×10^4 Kg/cm^2, the said rubber sheet reinforced by the polyethylene naphthalate fiber cords having an effective Young's modulus in the range of from 1.8×10^4 to 4.0×10^4 Kg/cm^2 in the longitudinal direction of the cords, and the cords being disposed in the breaker material so as to make an angle in the range of from 62.5° to 75° with the latitudinal direction of the strip.

According to a second aspect of the invention, there is provided in, or for use in, a radial tire, a tire breaker consisting of an annular sheet rubber member reinforced by parallel polyethylene naphthalate fiber cords, each cord having a Young's modulus in the range of from 7.0×10^4 to 27.0×10^4 Kg/cm^2, the said annular sheet rubber member reinforced by the polyethylene naphthalate fiber cords having an effective Young's modulus in the range of from 1.8×10^4 to 4.0×10^4 Kg/cm^2 in the longitudinal direction of the cords, and the cords being disposed in the sheet rubber member so as to make an angle in the range of from 62.5° to 75° to a line parallel to the axis of rotation of the tire.

For a better understanding of the invention, reference is made to the accompanying drawings, in which:

Figs. 1A and 1B are a schematic plan view of a radial tire breaker and a schematic sectional view taken in the radial direction of the tire respectively;

Fig. 2 is a graph showing the relation between the lateral rigidity and the cornering power for a radial tire;

Fig. 3 is a radial sectional view of a radial tire;

Figs. 4A and 4B are a plan view and an end view, respectively, of a breaker, consisting one or more cord-reinforced rubber sheets;

Fig. 5 is a curve, showing the relation between the cord angle of a beaker and its lateral rigidity;

Fig. 6 is a partial perspective view of a cord-reinforced rubber sheet;

Fig. 7 is a schematic diagram, showing cord dispositions at different cord angles;

Fig. 8 is a diagrammatic illustration of the direction-denoting system which is used in tire stress analyses;

Fig. 9 is a graph, showing the relation between cornering force and cornering power; and

Fig. 10 is a schematic representation of the parameters involved in determining cornering power.

General:

A typical radial tire, as shown in Fig. 3, comprises a pair of beads, a carcass extending between the beads a rubber coating on the outer surface of the carcass, and a tread mounted on the rubber coating along the outer periphery thereof with one or more breaker layers disposed between the tread and the rubber coating. The carcass is made of rayon, nylon, polyester, or any other carcass material of conventional crossply tires, as well as polyethylene naphthalate. Figs. 1A and 1B illustrate a breaker having four layers of folded construction, in which the first and the second layers are made by symmetrically folding a corded rubber sheet, and the third and the fourth layers are also made by symmetrically folding a corded rubber sheet. The folded construction is, however, not essential to the present invention, but any other suitable breaker construction, such as overlaid separate sheets, can also be used for fulfilling the purpose of the invention. Any number of sheets, e.g., two, three, four, or six sheets, can be incorporated in the breaker. Radial tires with breakers according to the present invention can be made by any of conventional methods for making radial tires.

In a prefererd embodiment of the invention a breaker is used which includes paired annular rubber sheets reinforced by the polyethylene naphthalate cords, two rubber sheets in each pair being symmetrically disposed relative to the equatorial direction of the breaker.

In order to optimize the performance characteristics of a radial tire, such as the wear-resistivity and the cornering power, it is necessary to minimize the deformation of the tire tread when the tire is run along a curved path. To this end, the breaker layer is required to have a high lateral rigidity, or a high resistivity against an outside

force applied thereto in a direction lateral to the equatorial direction thereof. In Fig. 4A, illustrating a tire breaker in an expanded form, the equatorial direction or the direction of equatorial tension is represented by a symbol T, and a lateral displacement w is caused in response to a lateral load W. The lateral rigidity S of the breaker is given by the ratio of the displacement w to the load W, namely, W/w.

Fig. 2 shows relations between the lateral rigidity S and the cornering power in a radial tire according to the present invention.

The cornering power is given by the quotient obtained by dividing the cornering force by the side slip angle for the cornering force, namely,

$$\text{cornering power} = \frac{\text{Cornering force}}{\text{Side slip angle}} = \tan\theta$$

θ being the angle between the abscissa and the rising portion of the side slip angle-cornering force characteristics in a graph in which the cornering force is plotted on the ordinate axis against the slip angle on the abscissa as in Figure 9. To understand in physical terms the nature of the side slip angle, frequently referred to as the slip angle, it should be noted that when a slip angle is given to a tire, the tire tends to move along a circular path. A centripetal force is generated by the friction between the road surface and the tire which is moving along the circular path. The cornering power is that component of such centripetal force which is perpendicular to the tire cruising direction. The physical relationship between these parameters is illustrated in Figure 10.

It is apparent from Figure 2 that as the lateral rigidity increases, the cornering power is improved. Generally speaking, the lateral rigidity S of a tire breaker consisting of corded rubber sheets can be increased by either of the following two approaches.

i) To raise the Young's modulus of the tire breaker for tension in the circumferential direction of the tire breaker.

ii) To raise the modulus of shearing rigidity of the tire breaker for lateral shearing load.

As long as the angle of the cords of corded rubber sheets of the breaker relative to the axial direction of the tire, i.e., the direction of the axis of rotation of the tire, is in the range of 45° to 90°, "the Young's modulus" decreases as the "the shearing modulus" increases, so that the breaker's lateral rigidity S assumes a maximum value when the cords in the breaker assume a certain angle with respect to the axis of tire rotation. In Fig. 1A, this angle of the cord relative to the axial direction of the tire, or a direction parallel to the axis of tire rotation, is represented by a symbol δ. Fig. 6 shows the relation among different symbols to be used in the following description of corded rubber sheets, which include

- E_x: Young's modulus of the sheet in the cord direction
- E_y: Young's modulus of the sheet lateral to the cord direction
- G_{xy}: Shearing modulus in the cord direction and in the direction lateral to the cord direction
- ν_x: Poisson's ratio in the cord direction
- ν_y: Poisson's ratio lateral to the cord direction

Fig. 5 shows the results of a test which has been carried out for determining the angle δ for giving the maximum lateral rigidity under the following conditions.

$E_x = 1.9 \times 10^4$ Kg/cm²
$E_y = 60$ Kg/cm²
$G_{xy} = 15$ Kg/cm²
$\nu_x = 0.5$

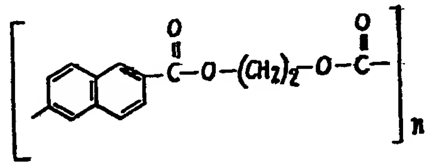
In the case of the tests as shown in Fig. 5, the maximum value of the lateral rigidity was given when the angle δ was 67.5°.

Thus, it is apparent that the performance characteristics of radial tires varies depending on the material for breaker cords and the disposition of the breaker cords. One of the essential feature osf the present invention is to provide for best combination of the breaker cord material and the angular disposition of such breaker cords.

Cord Material:

The polyethylene naphthalate fiber to be used in the radial tire breaker according

to the present invention consists of a polycondensate of naphthalenedicarboxylic acid and ethylene glycol, and its chemical structure is as follows.



The difference between the aforesaid polyethylene naphthalate and conventionally used polyester (e.g., polyethyleneterephthalate) is in that the benzene nuclei of the latter are replaced with naphthalene nuclei. The polyethylene naphthalate fiber to be used in the present invention has a melting point, a glass transition point, and a Young's modulus, which are all higher than the corresponding values of conventional polyethyleneterephthalate fibers, as shown in Table 1.

TABLE 1

Item	Polyethylene naphthalate	Polyethylene terephthalate
Melting point (°C)	275	260
Glass transition point (°C)	117	75
Young's modulus (Kg/cm^2)	3.0×10^5	1.4×10^5

Table 2 shows other physical properties of polyethylene naphthalate, in comparison with the properties of a typical rayon which is used in the breakers of conventional radial tires. It is apparent from Table 2 that, in comparison with the conventional rayon, the polyethylene naphthalate fibers have excellent properties suitable for radial tire breakers; for example, high mechanical strength, high static Young's modulus, high dynamic Young's modulus at high temperature, small creep at high temperature, high heat-resistivity, and high temperature for the peak of mechanical loss coefficient $\tan\delta$. The properties in Table 2 were measured by using the following method on cord specimens after treating them with adhesive followed by drying, which cord specimens were all twisted at a constant twisting coefficient, i.e., 0.44.

TABLE 2

Item		Polyethylene naphthalate	Rayon
Cord properties	Cord structure	1000d/2/2	1650d/3
	Twisting, Turns/10cm[2]	30×30	29×29
	Twisting coefficient	0.44	0.44
	Strength, Kg/cord	30.1	27.3
	Tenacity, g/denier	6.6	4.9
	Young's modulus, Kg/cm²	12.6×10^4	8.2×10^4
	Dynamic Young's modulus (100°C.) Kg/cm²	1.8×10^5	1.3×10^5
	Creep (100°C.) %	1.0	1.6
	Heat-resistivity, %	97	54
	Temperature for peak tanδ, °C	172	120
Young's modulus of rubber-cord compound body Kg/cm²		2.6×10^4	2.0×10^4

Cord properties:

(1) Strength:
The load at break, in Kg, when a 25-cm long cord specimen is elongated at a rate of 300-mm/minute, by using Type IS 2000 Autograph, made by Shimazu Manufacturing Company Limited.

(2) Tenacity:
The quotient obtained by dividing the strength by the correct size of the cord specimen.

(3) Young's modulus:
As determined on a 25-cm long cord specimen, by stretching the specimen at a rate of 300-mm/minute by using a Type-IS 2000 Autograph, made by Shimazu Manufacturing Company Limited.

(4) Dynamic Young's modulus:
As measured on a 4-cm long cord specimen at 100°C, by using a spectrometer made by Iwamoto Manufacturing Company Limited, under the conditions of frequency at 100 Hz/sec, static load of 600 g/cord, dynamic load of 300 g/cord.

(5) Creep:
As determined on a 15-cm long cord specimen at 100°C, by using a creep tester made by Iwamoto Manufacturing Company, with a load of 2.5 Kg/cord.

(6) Heat-resistivity:
The mechanical strength of a cord specimen after heating at 180°C in an oven followed by laying for 4 hours, as expressed in percent of the strength before the heating.

(7) Temperature for peak tanδ:
As determined under the same conditions as the dynamic Young's modulus.

Rubber sheet:

(8) Young's modulus of rubber-cord compound sheet:
As determined on a 3-cm wide 30-cm long sheet specimen, by stretching the specimen at a rate of 300mm/minute in the direction of the cord, which specimen was made by coating rubber on cords disposed at a rate of 7 cords/cm (18 cords/inch) and vulcanizing in a press.

The properties, as indicated in Table 2, suggest that the use of the polyethylene naphthalate fibers in the breaker of radial tires would improve their performance characteristics, as compared with the performance of radial tires with rayon-reinforced breakers.

It is generally believed that the high Young's modulus of radial tire breakers results in more efficient belting effects. The best way to use given fibers having a high Young's modulus is to use them at a low twisting rate. Thus, with the polyethylene naphthalate fibers used according to the present invention, the highest Young's modulus may be achieved by using the fibers as manufactured without twisting them. Under such conditions, the Young's modulus of the fibers is about 3×10^5 Kg/cm². Theoretically, a radial tire with a very high belting effects can be made by using such non-twisted polyethylene naphthalate fibers in its breaker. In practice, however, the workability of non-twisted fibers or fibers with a twisting rate of about 0.2 to 0.3 turns per 10-cm is very low; for instance, the process of dipping and the processing with rubber calenders is very difficult with such fibers. Furthermore, with a breaker consisting of non-twisted fibers or fibers with a very low twisting rate, the performance of radial tires in response to an external force, especially in response to impulsive shock, becomes poor. Accordingly, it may be concluded that the use of non-twisted fibers and fibers with a very low rate of twisting is not practicable.

A number of tests have been carried out to find a suitable rate of twisting. It has been found that, in the case of polyethylene naphthalate fibers having a Young's modulus of about 3.0×10^5 Kg/cm², as manufactured, one of the best structures is 1000 denier//2/2 cord, with a ply twist of 5 turns/10-cm and a cable twist of 5 turns/10-cm. The Young's modulus of the cord thus formed proved to be about 27.0×10^4 Kg/cm².

With the increase in the number of turns per unit length of the cord for twisting, the effective Young's modulus of the breaker is reduced to weaken its belting effects. At the same time, the mechanical strength of the breaker is also reduced with the increased twist. Thus, more cords must be used in a breaker as the twisting rate of the cord fiber increases. Excessively high twisting rate results in a cost rise. Besides, if polyethylene naphthalate fibers are twisted excessively, their strength is so drastically reduced that they become unfit for use in construction of radial tire breakers. From the manufacturing point of view, a very high twisting rate is not desirable because it causes the phenomenon of looping, or twisting, upon freeing the cords. It has been found that, with the aforesaid factors in mind, the Young's modulus of the polyethylene naphthalate cords which is suitable for providing proper performance characteristics of radial tires concommitant with convenience of manufacture falls within a range of from 7.0×10^4 to 27.0×10^4 Kg/cm².

The effective Young's modulus of the corded rubber sheet to be used in the radial tire breaker according to the present invention is very important, because it is one of the key factors affecting the lateral rigidity of the tire tread and the optimal cord angle of the cords depends on the desired level of such effective Young's modulus of the corded rubber sheet. It has been found that the effective Young's modulus of the corded rubber sheet should fall in a range of 1.8×10^4 to 4.0×10^4 Kg/cm². The upper limit of the aforesaid range corresponds to the effective Young's modulus of a corded rubber sheet with a maximum cord density, consisting of cords each having the highest Young's modulus of cord, i.e., 27.0×10^4 Kg/cm². The lower limit of the aforesaid range corresponds to the effective Young's modulus of a corded rubber sheet with a minimum cord density for allowing mechanical handling of the sheet, consisting of cords each having the minimum Young's modulus of 1.8×10^4 Kg/cm². The minimum cord density for the breaker rubber sheet was found to be about four cords/cm (or about 10 cords/inch). The cord density below the minimum density is not practicable, because individual cords in the rubber sheet at such a low density tend to move individually to make the rubber-calendering and the tire-building processes difficult. Theoretically, the loose connection among the highly sparsely disposed cords can be supplemented by using additional warps in the sheet, but it makes the sheet too costly to be practicable.

Cord angles:

In order to optimize the performance characteristics of a radial tire with such polyethylene naphthalate cords, a number of different breaker constructions have been studied through sample tests and theoretical analysis.

From sample tests, it was found that, with rubber sheets reinforced with polyethylene naphthalate fiber cords and having a Young's modulus of 1.8×10^4 to

4.0×10^4 Kg/cm², the highest lateral rigidity can be achieved with the angle δ of 62.5° to 75°, provided that the corded rubber sheets are symmetrically disposed relative to the equatorial direction of the tire. It was also found that such an optimal range of angle δ is valid regardless of the number of sheets in the breaker, e.g., two, three, four, or six sheets per breaker. From the standpoint of improving the handling characteristics of the tire, the breaker preferably includes paired rubber sheets reinforced by the polyethylene naphthalate cords, two rubber sheets in each pair being symmetrically disposed relative to the equatorial direction of the breaker.

In addition, theoretical analysis has been carried out on the relation between the lateral rigidity S and a cord angle α, which is complementary to the aforesaid angle δ, i.e., $\alpha = 90° - \delta$.

In the above defined elastic constants for a corded rubber sheet, the magnitude of the Young's modulus E_x of the rubberized sheet in the cord direction largely depends on the Young's modulus of the reinforcing cord disposed therein; while the Young's modulus lateral to the cord direction E_y, the shearing modulus G_{xy}, and the Poisson's ratio in the cord direction ν_x of such rubberized sheet largely depend on the Young's modulus of the rubber.

If a breaker is formed by overlaying two or more of such parallel-cord-reinforced rubberized sheets one on the other while disposing the cords therein at different cord angles α and β, as shown in Fig. 7, relative to the equatorial direction of a radial tire, the rigidity of the breaker thus formed becomes a function of a number of variables, inclusive of the number of such sheets, cord angles (α, β) of the cords in the different sheets, and the physical properties of the cords and rubbers constituting the different sheets.

Referring to Fig. 8, if the equatorial direction and the lateral or axial direction of the breaker thus formed are represented by suffixes ξ and η, respectively, the Young's modulus E_ξ in the equatorial direction and the shearing modulus $G_{\xi\eta}$ of the breaker consisting of such parallel-cord-reinforced rubberized sheets can be given as follows.

$$E_\xi = \frac{C_{11}C_{22}C_{33} - C_{11}C_{23}^2 + C_{12}C_{13}C_{23} - C_{12}^2 C_{33} + C_{12}C_{13}C_{23} - C_{13}^2 C_{22}}{C_{22}C_{33} - C_{23}^2} \qquad (1)$$

$$G_{\xi\eta} = \frac{C_{12}C_{23}C_{31} - C_{13}^2 C_{22} + C_{32}C_{21}C_{13} - C_{11}C_{23}^2 + C_{11}C_{22}C_{33} - C_{33}C_{12}^2}{C_{11}C_{22} - C_{12}^2} \qquad (2)$$

Here,

$$C_{11} = \frac{1}{2}\Bigg[\frac{E_y}{1-\nu_x\nu_y}\{(n_1+n_2)\cos^4\alpha + (n_3+n_4)\cos^4\beta\}$$

$$+\left(\frac{2\nu_x E_y}{1-\nu_x\nu_y} + 4G_{xy}\right)\{(n_1+n_2)\sin^2\alpha\cos^2\alpha + (n_3+n_4)\sin^2\beta\cos^2\beta\}$$

$$+\frac{E_x}{1-\nu_x\nu_y}\{(n_1+n_2)\sin^4\alpha + (n_3+n_4)\sin^4\beta\}\Bigg] \qquad (3)$$

$$C_{22} = \frac{1}{2}\Bigg[\frac{E_x}{1-\nu_x\nu_y}\{(n_1+n_2)\cos^4\alpha + (n_3+n_4)\cos^4\beta\}$$

$$+\left(\frac{2\nu_x E_y}{1-\nu_x\nu_y} + 4G_{xy}\right)\{(n_1+n_2)\sin^2\alpha\cos^2\alpha + (n_3+n_4)\sin^2\beta\cos^2\beta\}$$

$$+\frac{E_y}{1-\nu_x\nu_y}\left\{(n_1+n_2)\sin^4\alpha+(n_3+n_4)\sin^4\beta\right\}\Big] \qquad (4)$$

$$C_{33}=\frac{1}{4Z}\left[\frac{E_x+E_y-2\nu_x E_y}{1-\nu_x\nu_y}\left\{(n_1+n_2)\sin^2 2\alpha+(n_3+n_4)\sin^2 2\beta\right\}\right.$$

$$\left.+4G_{xy}\left\{(n_1+n_2)\cos^2 2\alpha+(n_3+n_4)\cos^2 2\beta\right\}\right] \qquad (5)$$

$$C_{12}=C_{21}=\frac{1}{Z}\left[\frac{\nu_x E_y}{1-\nu_x\nu_y}\left\{(n_1+n_2)(\cos^4\alpha+\sin^4\alpha)+(n_3+n_4)(\cos^4\beta+\sin^4\beta)\right\}\right.$$

$$\left.+\left(\frac{E_x+E_y}{1-\nu_x\nu_y}-4G_{xy}\right)\left\{(n_1+n_2)\sin^2\alpha\cos^2\alpha+(n_3+n_4)\sin^2\beta\cos^2\beta\right\}\right] \qquad (6)$$

$$C_{13}=C_{31}=\frac{1}{2Z}\left[\frac{E_y}{1-\nu_x\nu_y}\left\{(n_1-n_2)\cos^2\alpha\sin 2\alpha+(n_3-n_4)\cos^2\beta\sin 2\beta\right\}\right.$$

$$-\frac{E_x}{1-\nu_x\nu_y}\left\{(n_1-n_2)\sin^2\alpha\sin 2\alpha+(n_3-n_4)\sin^2\beta\sin 2\beta\right\}$$

$$\left.+\left(\frac{\nu_x E_y}{1-\nu_x\nu_y}+2G_{xy}\right)\left\{(-n_1+n_2)\sin 2\alpha\cos 2\alpha+(-n_3+n_4)\sin 2\beta\cos 2\beta\right\}\right] \qquad (7)$$

$$C_{23}=C_{32}=\frac{1}{2Z}\left[\frac{E_y}{1-\nu_x\nu_y}\left\{(n_1-n_2)\sin^2\alpha\sin 2\alpha+(n_3-n_4)\sin^2\beta\sin 2\beta\right\}\right.$$

$$-\frac{E_x}{1-\nu_x\nu_y}\left\{(n_1-n_2)\cos^2\alpha\sin 2\alpha+(n_3-n_4)\cos^2\beta\sin 2\beta\right\}$$

$$\left.-\left(\frac{xE_y}{1-\nu_x\nu_y}+2G_{xy}\right)\left\{(-n_1+n_2)\sin 2\alpha\cos 2\alpha+(-n_3+n_4)\sin 2\beta\cos 2\beta\right\}\right] \qquad (8)$$

n_1, n_2, n_3, and n_4: numbers of the rubberized sheets with the reinforcing cords disposed at angles $+\alpha$, $-\alpha$, $+\beta$, and $-\beta$, respectively;
$Z = n_1 + n_2 + n_3 + n_4$.

Referring to Figs. 4A and 4B, the applicants have simulated the lateral rigidity of the radial tire by a beam under a longitudinal tension T, to which beam a concentrated load W is laterally applied to the center thereof while holding the opposing

longitudinal edges of the beam stationary. If the deformation, or the strain, at the central portion of the beam, in response to such concentrated load W, is represented by *w*, the desired lateral rigidity S can be defined by a ratio W/w. Accordingly,

$$S = \frac{1 + \frac{11}{120} \cdot \frac{\ell^2 T}{E_\xi I} - \frac{T^2 \ell^2}{48 E_\xi I G_{\xi\eta} bh}}{\frac{\ell^3}{48 E_\xi I} + \frac{\ell}{8 G_{\xi\eta} bh} + \frac{3 \ell^3 T}{80 E_\xi I G_{\xi\eta} bh}} \quad (9)$$

here,

$$I = \frac{bh^3}{12}$$

b: thickness of the breaker
h: width of the breaker
l: effective length of the breaker

Since the quantities *b*, *h*, and *l* are constants, the lateral rigidity S of the above equation can be represented by the following function F.

$$S = F(E_x, E_y, G_{xy}, \nu_x, \nu_y, \alpha, \beta) \quad (10)$$

It has been found that the lateral Young's modulus E_y is very small, as compared with the cord direction Young's modulus E_x, and the value of the modulus E_y is determined mostly by the kind of the rubber utilized in the sheet. The variation ΔE_y of the modulus E_y, which is caused by the difference of the rubber material, is practically negligible, relative to the Young's modulus in the cord direction E_x. Thus, the magnitude of the Young's modulus lateral to the cord direction E_y can be treated as a constant for all practical purposes.

If the inextensibility of the cords is assumed, it has been known that the following relation can be derived.

$$G_{xy} = E_y/4$$

Since the lateral Young's modulus E_y can be assumed to be a constant, the shearing modulus G_{xy} can also be assumed as another constant. According to the reciprocal theory of Maxwell-Betty,

$$\frac{\nu_x}{E_x} = \frac{\nu_y}{E_y}$$

Thus,

$$\nu_y = (E_y/E_x) \cdot \nu_x$$

Since the quantity (E_y/E_x) can be assumed to be negligible, the Poisson's ratio lateral to the cord direction ν_y can also be assumed to be negligible.

As a result, the lateral rigidity S can be simplified into a function of only three independent variables E_x, α, and β; namely,

$$S = f(E_x, \alpha, \beta). \quad (10a)$$

It is now apparent that, for given Young's moduli in the cord direction E_x of individual rubberized sheets, the conditions for maximizing the lateral rigidity S of the breaker, namely, the values of α and β for maximizing S, can be determined from the equations (9) and (10a), while considering all the simplifications derived in the foregoing.

Despite the foregoing simplifications, rigorous analysis of the equation (9), with all the constants and variables substituted therein, is too complicated to carry out by pencil and paper alone. The applicants have conducted numerical analysis of the nature of the equation (9) by using a digital computer for three different breaker structures; namely, (1) a breaker with three parallel-cord-reinforced rubberized sheets,

(2) a breaker with four parallel-cord-reinforced rubberized sheets, and (3) a breaker with six parallel-cord-reinforced rubberized sheets. The results can be summarized as follows.

(1) Three-sheet breaker (with cord angles of α, $-\alpha$, and β, respectively):

i) for the Young's modulus in the cord direction in a range of

$$0 < E_x < 20{,}000\ \mathrm{Kg/cm^2}.$$

The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-5.0 \times 10^{-4} E_x + 29)^\circ \pm 5^\circ$$

$$\beta = 40^\circ \pm 5^\circ$$

ii) For the Young's modulus in the cord direction in a range of $20{,}000\ \mathrm{Kg/cm^2} \leq E_x \leq 80{,}000\ \mathrm{Kg/cm^2}$. The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-5.0 \times 10^{-5} E_x + 20)^\circ \pm 5^\circ$$

$$\beta = 40^\circ \pm 5^\circ$$

iii) For the Young's modulus in the cord direction in a range of E_x not smaller than $80{,}000\ \mathrm{Kg/cm^2}$. The lateral rigidity can be maximized with the following cord angles.

$$\alpha = 15^\circ \pm 5^\circ, \quad \beta = 40^\circ \pm 5^\circ$$

(2) Four-sheet breaker (with cord angles of α, $-\alpha$, β, and $-\beta$, respectively):

i) For the Young's modulus in the cord direction in a range of $0 < E_x \leq 25{,}000\ \mathrm{Kg/cm^2}$.
The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-5.0 \times 10^{-4} E_x + 27)^\circ \pm 5^\circ$$

$$\beta = (-5.0 \times 10^{-4} E_x + 35)^\circ \pm 5^\circ$$

ii) For the Young's modulus in the cord direction in a range of

$$25{,}000\ \mathrm{Kg/cm^2} < E_x \leq 80{,}000\ \mathrm{Kg/cm^2}.$$

The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-1.8 \times 10^{-4} E_x + 19)^\circ \pm 5^\circ$$

$$\beta = (1.0 \times 10^{-4} E_x + 20)^\circ \pm 5^\circ$$

iii) For the Young's modulus in the cord direction in a range of greater than $80{,}000\ \mathrm{Kg/cm^2}$. The lateral rigidity can be maximized with the following cord angles.

$$\alpha = 5^\circ \pm 5^\circ, \quad \beta = 28^\circ \pm 5^\circ$$

(3) Six-sheet breaker (two sheets each at cord angles of α and $-\alpha$, and one sheet each at cord angles β and $-\beta$, respectively):

i) For the Young's modulus in the cord direction in a range of

$$0 < E_x \leq 40{,}000\ \mathrm{Kg/cm^2}.$$

The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-2.0 \times 10^{-4} E_x + 26)^\circ \pm 5^\circ$$

$$\beta = (-2.0 \times 10^{-4} E_x + 26)^\circ \pm 8^\circ$$

ii) For the Young's modulus in the cord direction in a range of

$$40{,}000\ \mathrm{Kg/cm^2} < E_x \leq 80{,}000\ \mathrm{Kg/cm^2}.$$

The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-2.0 \times 10^{-4} E_x + 26)^\circ \pm 5^\circ$$

$$\beta = (5.0 \times 10^{-4} E_x - 2)^\circ \pm 8^\circ$$

iii) For the Young's modulus in the cord direction in a range of

$$80{,}000\ \mathrm{Kg/cm^2} < E_x \leq 100{,}000\ \mathrm{Kg/cm^2}.$$

The lateral rigidity can be maximized with the following cord angles.

$$\alpha = (-2.0 \times 10^{-4} E_x + 26)^\circ \pm 5^\circ$$

$$\beta = 38^\circ \pm 8^\circ$$

iv) For the Young's modulus in the cord direction in a range of greater than 100,000 Kg/cm². The lateral rigidity can be maximized with the following cord angles.

$$\alpha = 5^\circ \pm 5^\circ, \qquad \beta = 38^\circ \pm 8^\circ$$

In view of the above results of the analysis by a digital computer, the following general expression has been derived.

$$\alpha(x) = A \cdot f_1(x) + B \cdot f_2(x) + C \cdot f_3(x) \qquad (11)$$

$$\beta(x) = A \cdot g_1(x) + B \cdot g_2(x) + C \cdot g_3(x) \qquad (12)$$

where,

n: number of sheets in a breaker

$$\left.\begin{aligned} A &= \frac{(6-n)(4-n)}{3} \\ B &= \frac{(6-n)(n-3)}{2} \\ C &= \frac{(n-4)(n-3)}{6} \end{aligned}\right\} \qquad (13)$$

$$\begin{aligned} f_1(x) &= 0.31x^2 - 3.84x + 26.8^\circ \pm 5^\circ && (\text{for } 0<x<8.0) \\ &= 15^\circ \pm 5^\circ && (\text{for } 8.0 \leq x) && (14) \\ g_1(x) &= 40^\circ \pm 5^\circ && (\text{for all } x) && (15) \\ f_2(x) &= 0.27x^2 - 4.73x + 26.5^\circ \pm 5^\circ && (\text{for } 0<x<8.0) && (16) \\ &= 30^\circ \pm 5^\circ && (\text{for } 8.0 \leq x) \\ g_2(x) &= 0.5x^2 - 4.47x + 33^\circ \pm 5^\circ && (\text{for } 0<x<9.0) && (17) \\ &= 5^\circ \pm 5^\circ && (\text{for } 9.0 \leq x) \end{aligned}$$

$$f_3(x) = -2.0x + 25^\circ \pm 5^\circ \quad (\text{for } 0<x<10.0) \qquad (18)$$
$$= 5^\circ \pm 5^\circ \quad (\text{for } 10.0 \leq x)$$

$$g_3(x) = 0.81x^2 - 5.22x + 28^\circ \pm 8^\circ \quad (\text{for } 0<x<8.0) \qquad (19)$$
$$= 38^\circ \pm 8^\circ \quad (\text{for } 8.0 \leq x)$$

$$x = \frac{E_x}{10^4 Kg/cm^2} \qquad (20)$$

In the case of a three-sheet breaker in which only the paired sheets meet the requirement that the cords therein are disposed so as to make an angle in the range of from 62.5° to 75° with the longitudinal direction of the strip, the above general expression reduces as follows:—

$$\alpha(x) = f_1(x) = 0.31x^2 - 3.84x + 26.8^\circ \pm 5^\circ$$
$$(\text{for } 0<x<8.0)$$
$$= 15^\circ \pm 5^\circ \ (\text{for } 8.0 \leqslant x)$$
$$\beta(x) = g_1(x) = 40^\circ \pm 5^\circ \ (\text{for all } x)$$
$$X = \frac{E_x}{10^4 \ Kg/cm^2}$$

As the value of the Young's modulus of the rubberized sheet in the cord direction E_x, the initial modulus for a strain of 2 to 3% can be used.

A series of tests were carried out by making different tire specimens of the invention for verifying the above computer analysis, and for checking the actual effects of the tire breakers having such Young's moduli and cord angles. As a result, it was confirmed that the relation of the equations (11) and (12) are in good agreement with the outcome of the tests.

Furthermore, for the given effective Young's modulus $E_x = 1.8 \times 10^4$ to 4.0×10^4 Kg/cm^2 for the rubber sheet reinforced by polyethylene naphthalate fiber cords, according to the present invention, the optimal range of the cord angle α was computed on the condition of a four sheet breaker with $\alpha=\beta$. The preferable range of the cord angle α proved to be 15° to 27.5°, or 62.5° to 75° in terms of the angle δ of Fig. 1A.

Examples:

The invention will now be described in further detail, by referring to Examples.

Example 1:

Polyethylene naphthalate yarn of 1000 denier as manufactured, which had a Young's modulus of substantially 3.0×10^5 Kg/cm^2, was twisted into 1000 denier// 2/2 cords with a ply twist of 30 turns/10 cm and a cable twist of 30 turns/10 cm. The cord had a Young's modulus of 11.0×10^4 Kg/cm^2 after treating with adhesive followed by drying. The cords thus prepared were woven at a cord density of 7 cords/ cm (or 18 cords/inch), coated with rubber, and vulcanized by a press, for preparing corded rubber sheets. A 3-cm wide specimen was prepared from the rubber sheet, to determine its Young's modulus with a chuck distance of 30 cm. It was found that the Young's modulus E_x of the corded rubber sheet was 2.6×10^4 Kg/cm^2.

By assuming a breaker construction of Figs. 1A and 1B, with the cords of the first and third sheets being disposed in symmetry with the second and fourth sheets with respect to the equatorial direction of the tire, the relation of the cord angle and the lateral rigidity was calculated by the aforesaid equation (11), and the results are shown in Table 3.

TABLE 3

4-sheet breaker

Angle δ (degree)	55	57.5	60	62.5	65	67.5	69	70	72.5	75	77.5	80
Lateral rigidity S (Kg/cm)	191	214	231	250	266	274	276	274	264	242	186	180
Cornering power Kg/degree	52.0	57.0	60.0	66.0	67.0	67.8	69.0	67.0	64.0	62.0	51.0	49.5

It is apparent that the maximum lateral rigidity was obtained by the angle $\delta = 69°$ between the cord and the axial direction of the radial tire breaker.

On the other hand, ten specimens of radial tires with 4-sheet breakers having the aforesaid corded rubber sheets disposed at different angles were made through a conventional method, and their handling characteristics, more particularly their cornering power, were measured, together with the lateral rigidity of the respective breakers. The relation between the cornering power and the lateral rigidity was thus determined, as shown in Fig. 2. It is apparent from Fig. 2 that the cornering power of the radial tire substantially linearly increases with the lateral rigidity.

Judging from the rigidity of the breaker and the cornering power of the radial tires, it was found that the preferable range of the angle δ between the polyethylene naphthalate cords and the axial direction of the radial tire breaker is 62.5° to 75°.

Example 2:

The same polyethylene naphthalate yarn as Example 1 was twisted into 1000 denier//2/2 cords with a ply twist of 10 turns/10 cm and a cable twist of 10 turns/10 cm. The cord had a Young's modulus of 24.7×10^4 Kg/cm² after adhesive treatment followed by drying. The cords were woven at a cord density of 10 cords/cm (or 26 cords/inch), and coated with rubber for producing a corded rubber sheet. A 3-cm wide specimen was prepared from the rubber sheet, to determine its Young's modulus with a chuck distance of 30 cm. The Young's modulus E_x thus determined was 3.5×10^4 Kg/cm².

The variation of the lateral rigidity S of the breaker with such corded rubber sheets for different angles δ between the radial tire breaker cord and the axial direction of breaker was computed in the same manner as Example 1. The maximum value

of the lateral rigidity was found at the angle δ of 71°. The fact that the angle for the maximum later rigidity in Example 1 is different from that in Example 2 indicates that the optimal design of the radial tire breaker according to the present invention depends on the properties of the material, i.e., the effective Young's modulus E_x of the corded rubber sheet.

Test radial tires were made with the 4-sheet breakers of this Example, and the results of field tests of the test radial tires proved an improvement of the cornering power by about 35% over the maximum cornering power of Example 1.

Such test results indicate that the angle δ between the cords in the breaker and the axial direction of the breaker plays a decisive role in the performance characteristic of radial tires. In other words, if cords with a high Young's modulus were carelessly incorporated in a radial tire breaker, the cornering power of a radial tire with such breaker may sometimes be much lower than that of another radial tire with a breaker made of cords having a comparatively small Young's modulus but disposed properly.

Example 3:

The same polyethylene naphthalate yarn as Example 1 was twisted into 1000 denier//2/2 cords with a ply twist of 30 turns/10 cm and a cable twist of 30 turns/10 cm. The cord had a Young's modulus of 11.0×10^4 Kg/cm² after adhesive treatment followed by drying. The cords were woven at a cord density of 7 cords/cm (or 18 cords/inch) and coated with rubber, so as to produce a corded rubber sheet having a Young's modulus E_x of 2.6×10^4 Kg/cm².

Four test radial tires were prepared with 4-sheet breakers consisting of the corded rubber sheets thus prepared and disposed at the angle δ of 75° by using a conventional method. The carcass of the test radial tires consisted of plies with 1650 denier/2 rayon cords disposed in parallel with the axis of rotation of the tire. The test radial tires thus prepared were subjected to high-speed durability test on a drum tester. The service life of the test radial tire, in terms of breaker separation, proved to be about 30% longer than the corresponding service life of reference radial tires having breakers each having 1650 denier/3 rayon cords disposed at an angle $\delta=73°$. The heat generation during running of the test radial tires proved to be lower than that of the reference tires with rayon breakers. In the measurement of the mechanical strength after the running test, the polyethylene naphthalate fibers showed no deterioration, but the rayon fibres showed about 5% deterioration.

The test radial tires with polyethylene naphthalate cords showed better performance than the reference tires with rayon cords both in field tests and rolling-resistance tests.

Example 4:

Specimens of 2-sheet breakers and 6-sheets breakers were made by using the same corded sheets as Example 3 by a known method, and test radial tires were made with such breakers. The different angles δ between the cords and the axial direction of the tire breaker were used in the different specimens. The relations between the angle δ and the cornering power of the test radial tires with such breaker specimens were determined by a drum tester. The results are shown in Table 4.

TABLE 4

Angle δ (degree)		60	62.5	65	67.5	69	70	71	72.5	75	80
Cornering power (Kg/degree)	2-sheet breaker	43	45	50	51.1	51.5	52	51	48	47	37
	6-sheet breaker	66	70	76.5	78.0	78.5	79.2	80	74	72	65

From the four Examples, it can be seen that the performance of radial tires can greatly be improved by using breakers made of polyethylene naphthalate cords disposed at proper angles.

Salient features of the present invention are as follows.

(1) The radial tire breaker of the present invention improves the handling characteristics and stability of radial tires, especially their cornering power.

(2) The wear-resistivity of the radial tire tread is improved.

(3) Optimal use of the material is made by properly designing the angular disposition of the radial tire breaker while considering the properties of the material.

(4) Various properties of radial tires for continuous long run are improved; such as tire growth, stability, and durability.

WHAT WE CLAIM IS:—

1. A strip of radial tire breaker material consisting of a rubber sheet reinforced by parallel polyethylene naphthalate fiber cords, each cord having a Young's modulus in the range of from 7.0×10^4 to 27.0×20^4 Kg/cm^2, the said rubber sheet reinforced by the polyethylene naphthalate fiber cords having an effective Young's modulus in the range of 1.8×10^4 to 4.0×10^4 Kg/cm^2 in the longitudinal direction of the cords, and the cords being disposed in the breaker material so as to make an angle in the range of from 62.5° to 75° with the latitudinal direction of the strip.

2. In, or for use in, a radial tire, a tire breaker consisting of an annular sheet rubber member reinforced by parallel polyethylene naphthalate fiber cords, each cord having a Young's modulus in the range of from 7.0×10^4 to 27.0×10^4 Kg/cm^2, the said annular sheet rubber member reinforced by the polyethylene naphthalate fiber cords having an effective Young's modulus in the range of from 1.8 to 10^4 to 4.0×10^4 Kg/cm^2 in the longitudinal direction of the cords, and the cords being disposed in the sheet rubber member so as to make an angle in the range of from 62.5° to 75° to a line parallel to the axis of rotation of the tire.

3. A radial tire breaker according to Claim 2, wherein the breaker includes paired annular rubber sheets reinforced by the polyethylene naphthalate cords, the two rubber

sheets in each pair being symmetrically disposed relative to the equatorial direction of the tire.

4. A radial tire breaker according to Claim 3, wherein the breaker includes one pair of corded sheets.

5. A radial tire breaker according to Claim 3, wherein the breaker includes two pairs of corded sheets.

6. A radial tire breaker according to Claim 3, wherein the breaker includes three pairs of corded sheets.

7. A radial tire breaker according to Claim 2, wherein the breaker comprises one pair of the corded sheets and a third corded sheet, the two rubber sheets in the pair being symmetrically disposed relative to the equatorial direction of the breaker.

8. A radial tire breaker according to Claim 7, wherein the cords of the paired sheets are disposed at angles of $+\alpha$ and $-\alpha$ to the equator of the tire breaker and the cords of the third corded sheets ar disposed at an angle of β to the equator of the line breaker, the angle α being larger than 15° but smaller than 27.5°, depending on the initial Young's modulus E_x of each of said rubberized sheets at a strain of 2 to 3%, which angles lie within the following ranges:

$$
\begin{aligned}
\alpha(x) = f_1(x) &= 0.31x^2 - 3.84x + 26.8° \pm 5° && \text{(for } 0 < x < 8.0\text{)} \\
&= 15° \pm 5° && \text{(for } 8.0 \leqslant x\text{)} \\
\beta(x) = g_1(x) &= 40° \pm 5° && \text{(for all x)}
\end{aligned}
$$

$$x = \frac{E_x}{10^4 \text{ Kg/cm}^2}$$

9. A radial tire breaker according to any one of Claims 3 to 6, wherein the angles between the equator of the tire breaker and the cords are selected from the following angles, $+\alpha$, $-\alpha$, $+\beta$, and $-\beta$, α and β being larger than 15° but smaller than 27.5°, depending on the initial Young's modulus E_x of each of said rubberized sheets at a strain of 2 to 3%,

$$
\begin{aligned}
\alpha(x) &= A.f_1(x) + B.f_2(x) + C.f_3(x) \\
\beta(x) &= A.g_1(x) + B.g_2(x) + C.g_3(x)
\end{aligned}
$$

where,

n : number of the sheets in the breaker,

$$A = \frac{(6\text{-}n)(4\text{-}n)}{3}, \qquad C = \frac{(n\text{-}4)(n\text{-}3)}{6}$$

$$B = \frac{(6\text{-}n)(n\text{-}3)}{2},$$

$$
\begin{aligned}
f_1(x) &= 0.31x^2 - 3.84x + 26.8° \pm 5° && \text{(for } 0 < x < 8.0\text{)} \\
&= 15° \pm 5° && \text{(for } 8.0 \leq x\text{)} \\
g_1(x) &= 40° \pm 5° && \text{(for all x)} \\
f_2(x) &= 0.27x^2 - 4.73x + 26.5 \pm 5° && \text{(for } 0 < x < 8.0\text{)} \\
&= 30° \pm 5° && \text{(for } 8.0 \leq x\text{)} \\
g_2(x) &= 0.5x^2 - 4.47x + 33° \pm 5° && \text{(for } 0 < x < 9.0\text{)} \\
&= 5° \pm 5° && \text{(for } 9.0 \leq x\text{)} \\
f_3(x) &= -2.0x + 25° \pm 5° && \text{(for } 0 < x < 10.0\text{)} \\
&= 5° \pm 5° && \text{(for } 10.0 \leq x\text{)} \\
g_3(x) &= 0.81x^2 - 5.22x + 28° \pm 8° && \text{(for } 0 < x < 8.0\text{)} \\
&= 38° \pm 8° && \text{(for } 8.0 \leq x\text{)}
\end{aligned}
$$

$$x = \frac{E_x}{10^4 \text{ Kg/cm}^2}$$

10. A radial tire breaker according to claim 9, wherein said tire breaker includes four annular rubber seats having cords disposed at angles of $+\alpha$, $-\alpha$, $+\beta$, and $-\beta$, respectively, relative to the equator of said tire.

11. A radial tire breaker according to claim 9, wherein said tire breaker includes six annular rubber sheets having cords disposed at different angles relative to the equator of said tire; namely, two sheets at $+\alpha$, two sheets at $-\alpha$, one sheet at $+\beta$, and one sheet at $-\beta$.

12. A strip of radial tire breaker material as claimed in Claim 1, substantially as hereinbefore described.

13. A strip of radial tire breaker material as claimed in Claim 1, substantially as described in any one of the foregoing Examples.

14. In, as for use in a radial tire, a tire breaker as claimed in Claim 2, substantially as described in any one of the foregoing Examples.

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Fig. 1A

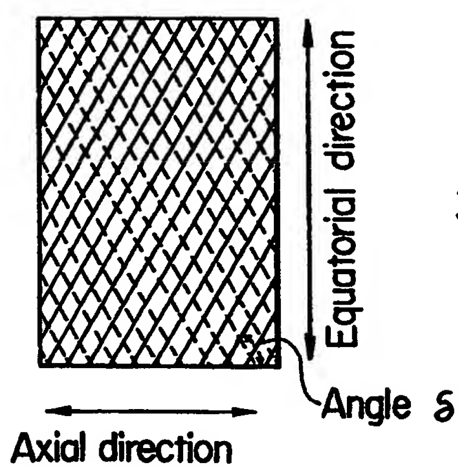
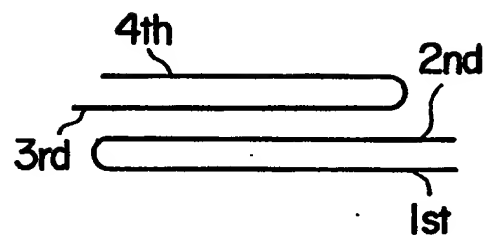

Equatorial direction
Angle δ
Axial direction

Fig. 1B


4th
2nd
3rd
1st

1,310,316 COMPLETE SPECIFICATION
5 SHEETS *This drawing is a reproduction of the Original on a reduced scale.*
SHEET 2

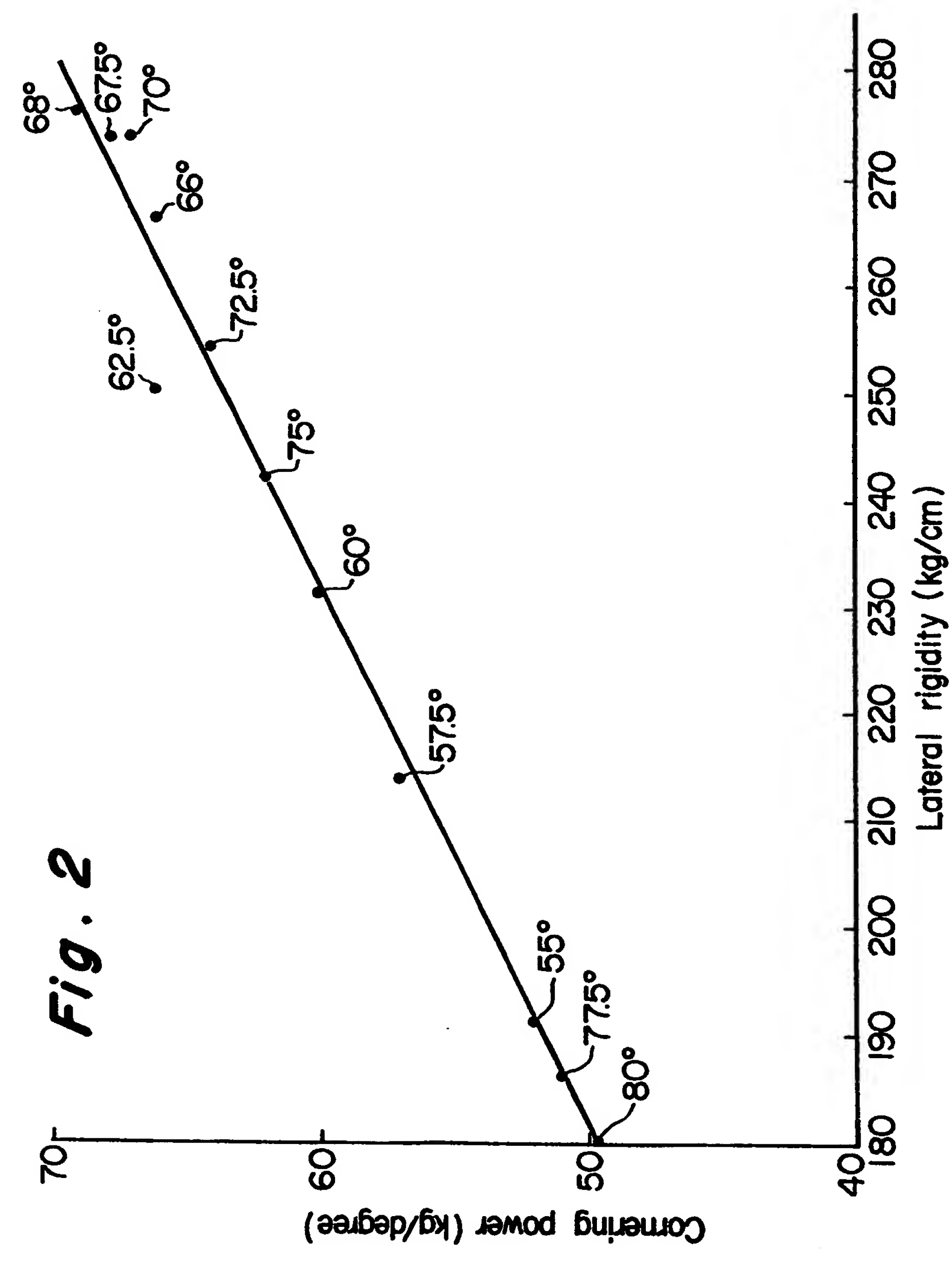


Fig. 2

Fig. 3

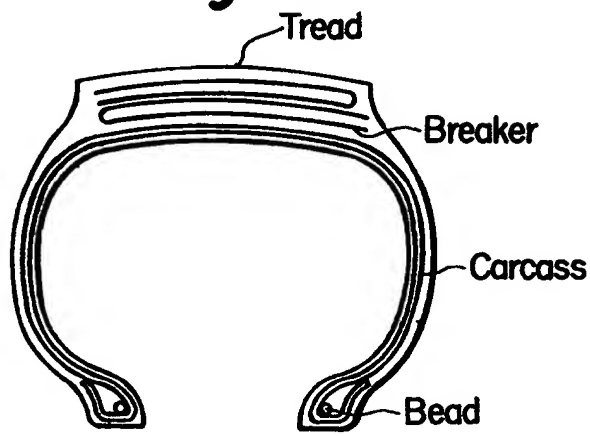


Fig. 4A

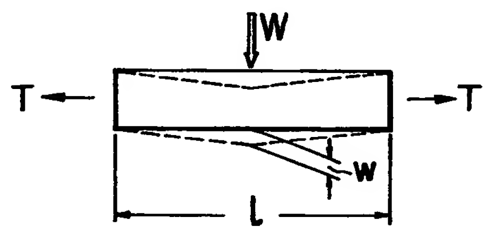


Fig. 4B

Fig. 5

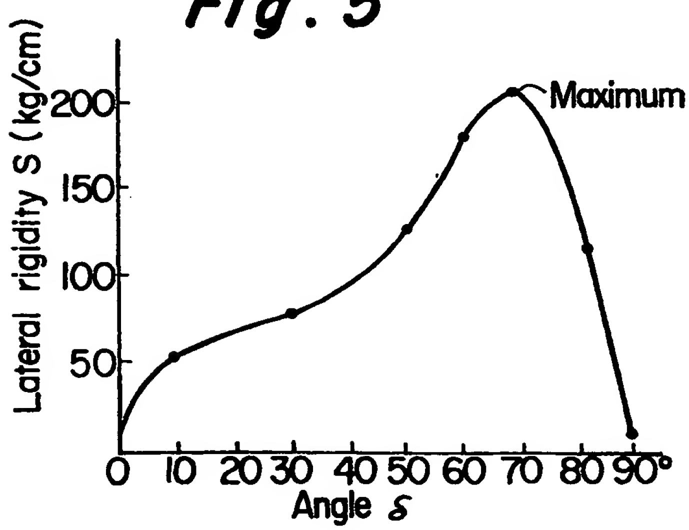


Fig. 6

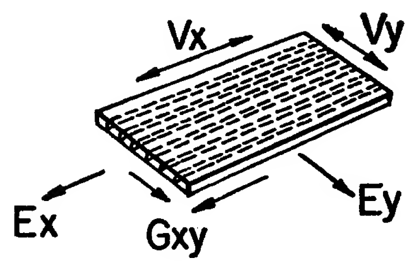


Fig. 7

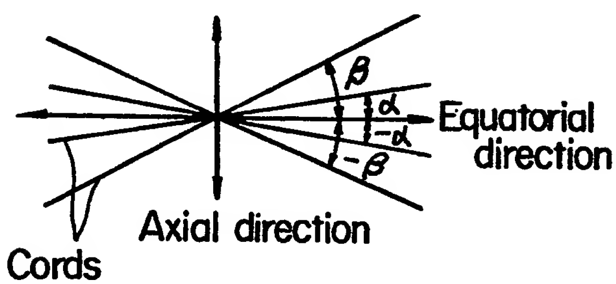


Fig. 8

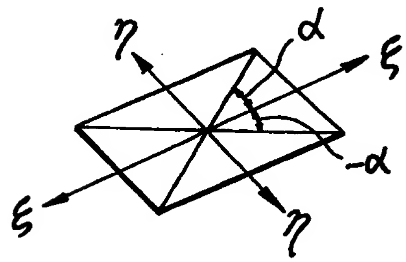
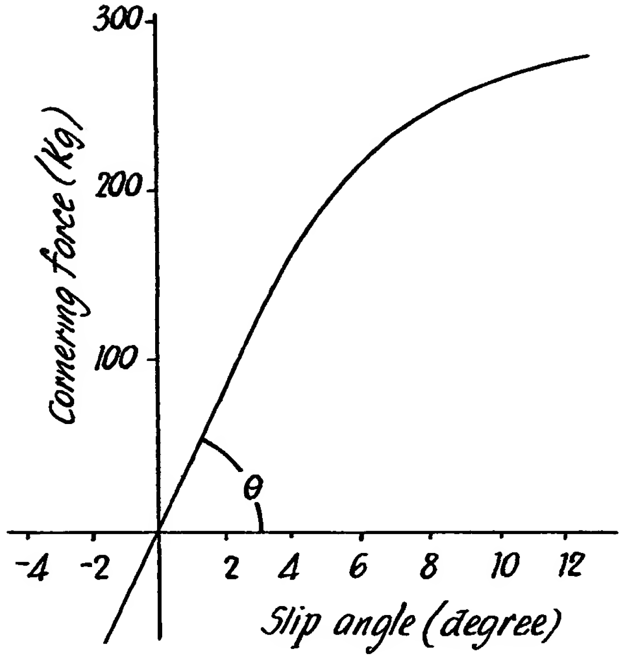


FIG. 9


300
200
100
Cornering force (Kg)
θ
-4
-2
2
4
6
8
10
12
Slip angle (degree)

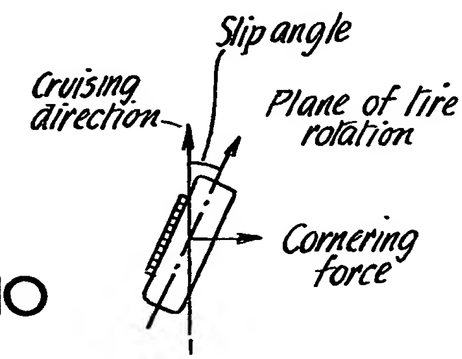

Slip angle
Cruising direction
Plane of tire rotation
Cornering force

FIG. 10